

functionality relative to the certain functionality of the first radio frequency chains; and performing beamforming with the multiple beams to the multiple users.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the attached Drawing Figures:

[0015] FIG. 1, including FIGS. 1A and 1B, illustrates an exemplary massive MIMO antenna concept with a few antenna elements (AEs) having full RF chains and most other AEs being limited to very simple on-off PAs for the dumb RF chains;

[0016] FIG. 2, including FIGS. 2A and 2B, illustrates a transmitter comprising a proposal combining possible very slim, low cost RF-chains that avoid ADCs, have constant amplitude PAs and simple RF filters due to, e.g., half-rate switching and conventional RF frontends;

[0017] FIG. 3 illustrates over-the-air combining of half rate switched signals from at least two antennas and the corresponding narrowed spectrum allowing for low cost compact size RF filters;

[0018] FIG. 4 illustrates a system in which the exemplary embodiments may be practiced;

[0019] FIG. 5 is a block diagram of an exemplary logic flow diagram for use of low effort massive MIMO antenna arrays, and that illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, and/or functions performed by logic implemented in hardware, in accordance with exemplary embodiments herein;

[0020] FIG. 6, including FIGS. 6A and 6B, illustrates the following: in FIG. 6A, the y-axis is the abs (sum of precoding weights) (where abs() is absolute value) relative to the number of Tx antennas (x-axis) or is on-off switching of PAs according to abs (sum weight); FIG. 6B is a constellation diagram of Tx signals for all Tx antennas with/without on-off switching of PAs; note certain points are all on a circle—or at zero—due to constant signal strength, while others can take any value within this circle;

[0021] FIG. 7, including FIGS. 7A and 7B, illustrates a CDF of Rx signal strength (FIG. 7A) and phase offset (FIG. 7B) for all three UEs for PA on-off switching; and

[0022] FIG. 8, including FIGS. 8A and 8B, illustrates in FIG. 8A a CDF of precoding powers for perfect precoding for UEs one through three and precoding power per UE for simple PA solution and in FIG. 8B a curve includes the overall Tx power required with conventional 4x3 precoding (e.g., four antennas and three UEs).

DETAILED DESCRIPTION OF THE DRAWINGS

[0023] As indicated above, it would be beneficial to reduce the costs for the implementation of massive MIMO arrays, which is a real challenge taking the high number of antenna elements into account. Different approaches have been proposed for the implementation of massive MIMO arrays, but even first massive MIMO demonstrators are typically bulky, costly and complex. For measurements, often signals measured sequentially have to be stored and combined offline for further analysis.

[0024] Several approaches can be found for the design of massive MIMO antenna arrays, where the goal is always to reduce the required effort and costs while keeping beamforming gains and flexibility for beam steering. For instance, see “Massive MIMO For Next Generation Wireless Systems”,

Erik G. Larsson, Ove Edfors, Fredrik Tufvesson, Thomas L. Marzetta, IEEE Communications Magazine, VOL. 52, NO. 2, PP. 186-195, February 2014.

[0025] In a first approach (Approach 1), use is made of only $N \ll N_{AE}$ number of RF chains. It is noted that an RF chain is also referred to as an RF frontend herein. The variable N is adapted to the maximum number of simultaneously served users, while N_{AE} is the overall number of antenna elements. Practically, this means that only a number of, e.g., $N=10$ instead of $N_{AE}=100$ of RF chains might be needed. This led for example to hybrid digital-analog antenna concepts, where the digital signals per UE are beam-steered by analog phase shifters. This will lead to relatively poor analog distribution networks including a relative high insertion loss for the Tx signals.

[0026] Alternatively, one might share the active RF frontends to several antenna elements, which significantly affects the achieved beam patterns and provides less flexibility in forming and steering of beams.

[0027] In a second approach (Approach 2), use is made of low cost RF frontends. Several research groups have tried and are still trying to use low cost RF chains per antenna element. One example includes the active antenna activities mentioned above. Other groups try to reuse the already fully optimized RF frontends from 3 GPP user devices, which seem to be available at costs of about 30 Euros per RF frontend. For a 256 antenna element array this still would incur costs of upwards of 8000 Euros (about 11,000 U.S. dollars).

[0028] In a third approach (Approach 3), the functionality of RF frontends is minimized. Massive MIMO entails an overprovisioning of antenna elements compared to the number of served users. This might allow for some form of over-the-air generation of Rx signals by suitable combining of many different Tx signals from different antenna elements.

[0029] This opens the possibility for RF chains with limited functionality such as much lower Tx power, limited peak to average power ratios of the PA, low resolution ADCs having only few bits, etc., which will reduce the cost per RF frontend potentially significantly.

[0030] An exemplary embodiment uses the lowest functionality per RF chain, i.e., in one case, a simple on-off switching of PAs together with some phase shifting of the RF signal may be used. This can be seen as a 1-bit ADC per PA, but by direct control from the baseband chip any further ADC component might become superfluous (e.g., the baseband chip could approximate the 1-bit ADC output).

[0031] One main aspect herein combines these extremely “dumb” RF frontends with a limited set of full performance RF frontends having high linearity, high resolution ADCs, high quality RF filters, high back off, and the like. The dumb RF frontends can be then seen as booster antennas for the high quality RF frontends.

[0032] The system works according to a “dirty paper” precoding concept, i.e., the dumb antenna elements generate, by over-the-air combining, a beamformed and precoded signal, which is as close as possible to the intended Rx signals at the currently served users. As is known, dirty paper coding is a technique for efficient transmission of digital data through a channel subjected to some interference known to the transmitter. The technique consists of precoding the data in order to cancel the effect caused by the interference. The high quality RF frontends are being used herein to generate a compensation signal, which generates the finally intended Rx signal at UE side. For a high number of booster antennas, the